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CBR correlation with index properties of natural soils of selected failed roads in southeastern Nigeria

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ABSTRACT

Poor conditions of subgrade soils have been noted as one of the major causes of pavement failures. The strength of subgrade soils are measured by their CBR values. Soil samples were collected from three different locations of total failure in Awkuzu, Ugwuoba and Arondizogu all in southeastern Nigeria. Index properties as well as the compaction characteristics of the soil were determined. The soils have more than 35% of their particles passing the No 200 BS sieve and were classified as silty-clay materials in line with AASHTO soil classification. Their liquid limits (LL) and plasticity indices (PI) fall within the ranges of 49% to 78.4% and 24% to 37.3% respectively. Therefore, they can be said to belong to the soil group A-7-5, showing that their major constituents are clayey soils which have fair to poor subgrade rating. Three-point CBR at OMC was carried out on the soils and their values ranged from 1.8% to 2%. When the CBR values were correlated with other properties of the soil, a perfect negative correlation (-1.0) existed with the OMC, strong positive correlation of 0.97 existed with the MDD while the index properties of the soils showed negative weak to moderate correlation within the ranges of -0.32 to -0.50.

Keywords: CBR; OMC; natural soils; pavement failures

1. INTRODUCTION

Failures in road pavements have been considered a major cause of most of the crashes recorded in Nigerian roads. Road transportation forms the basic means of transporting goods and services from one part of Nigeria to the other. Proper design, planning and construction of various layers of these road pavements are thus of great significance towards the enhancement of economic growth of the country [12]. Nigeria maps out huge financial resources annually for her transportation sector, this notwithstanding, many of the newly built and rehabilitated roads in the country keep failing within short periods of their completion [3]. These failures, over the years, has resulted in loss of lives, damage of goods, grounding of adjoining properties to the roads as well as loss of several man hours. Abia, Anambra, Ebony, Enugu and Imo are the five states that make up the southeastern Nigeria. The roads in this region are predominantly of the

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flexible pavement type and like other roads in the country, have always recorded incessant pavement failures.

As a multi-layered system, flexible pavements are made up of the surfacing, base course, sub-base and subgrade [17]. This type of pavement has a basic function of receiving traffic loads and transmitting them to the subgrade through its various layers. Therefore, the conditions and properties of these component layers provide a basis for the strength and stability of this type of pavement. When the underlying layers are in favourable conditions, the surfacing should be stable enough as to provide a good riding surface, proper skid resistance, sufficient reflection of light and good drainage [6].

These incessant rate of failures of the road pavements have been of great concern to the researchers and highway engineers in this part of the world. As a result, a lot of researches have been conducted in a bit to establish the root causes of these incessant failures. [18], in his investigation of the causes of pavement deterioration in Khartoum State of Sudan, buttressed the fact that one of the most common causes of pavement distresses is when the road subgrade contains expansive soils. Also, in their engineering geological investigation of highway pavement failure in basement complex terrain of southwestern Nigeria, [15] found out that the failure of the highway under study was hugely a function of the geotechnical properties of the subgrade soils. [1], [13] and [2] in their studies equally found out that poor subgrade soils are the predominant geological factors responsible for the susceptibility of road pavements to fail. Some of the recorded failures in the subgrade include: excessive subgrade rutting, aggregate contamination or degeneration, subgrade pumping, poor drainage, frost action, swelling of soils, differential embankment settlement, embankment and cut slope stability, liquefaction, collapsing soil and karstic formation [10].

The need for thorough geological/geotechnical investigation of the natural soils of proposed and existing roads cannot, therefore, be overemphasized. When the geological investigation is thorough, the weathering history of the parent rock (subgrade) can be ascertained. Also, the information about the underlying aquifer can be gotten, with special notification about the water table and prevalence of artesian situations. Typically, subgrade soils are characterized by their resistance to deformation under load, which is a function of their California Bearing Ratio (CBR) values [8]. California State Highways Department developed CBR to evaluate the strength of roads' subgrades and is applied in the design of highway and airfield pavements [11].

2. METHODOLOGY

The natural soils (weathered parent rock materials) were collected at about 6m away from the distressed portions of the selected road pavements. This was done at the following locations: Awkuzu in Anambra state, along Onitsha-Awka-Enugu Highway (latitude 6,24041243621663N and longitude 6.952883563935757E), Ugwuoba in Enugu state, along Enugu-Onitsha Expressway (latitude 6.24765743243533N and longitude 6.964179016649723E) and Arondizuogu in Imo state, along Awka-Okigwe road (latitude 5.8885361834091565N and longitude 7.160973362624645E). In each of the selected locations, a test pit (bore hole) of about 0.75m diameter was dug. Soil samples were collected at a depth of 1m from each of the dug bore holes.

2.1 Geology of the Study Area

Anambra state lies within the Anambra basin which is made up of Enugu Shale, Mamu Formation, Ajali Sandstone, and Nsukka Formation. Anambra basin, according to [9], is one of the energy-rich inland sedimentary basins in Nigeria and it is comprised of nearly a triangular embayment which covers about 300km^2 and has an approximately sedimentary thickness of 9km. In Anambra state, Enugu Shale is the oldest formation and it is exposed in different locations including the areas around the Enugu-Onitsha Expressway.

Enugu state is located in the Cross River basin and the Benue trough. Three distinct formations are exposed in this area, namely: Enugu Shale, Mamu Formation and Ajali Formation. According to [16], the region is made up of Precambrian basement rock which is covered with coal-bearing sediments from the cretaceous and tertiary age. The hills at Enugu may reach up to 1,000 meters in the extreme. Majority of the highlands and lowlands in Enugu are underlain by sandstone and shale respectively.

Imo is located in the Niger-Delta basin and underlain by the Ogwashi-Asaba and the Benin Formation. The Ogwashi-Asaba Formation is made up of an alternation of sands and clays as well as grits and lignites, while the Benin Formation are made up of sands and sandstones which are which are coarse to fine-grained and are commonly granular textured [4]. As a result, the state is rich in natural resources such as white clay, fine sand, and limestone.

2.2. Materials

Soil sample collected from Anambra was denoted as SS_A, the one from Enugu state was denoted as SS_B, while the sample from Imo is labeled as SS_C. These samples were collected at a depth of 1000mm at the different selected locations.

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2.3. Methods

The various soil samples were tested in the laboratory in line with BS 1377. To classify the soils and determine their index properties, gradation test and Atterberg limits tests were carried out on the samples. British standard light (BSL) compaction and CBR test were also conducted on the samples. Remolded samples for soaked CBR were prepared based on the optimum moisture content (OMC) and maximum dry density (MDD) obtained from BSL compaction. Based on the soaked CBR test results, correlation coefficients were obtained for the 3 different soil samples relating to each other.

3. RESULTS AND DISCUSSION

Results of various laboratory tests carried out on the samples are presented below:

Table 1: Index Properties and Compaction Characteristics of Soils

Properties	SS_A	SS_B	SS_C
Grain size distribution			
% retained in No. 200 sieve	3.3	3.4	2.5
% passing through No. 200 sieve	68.9	38.9	76.7
Atterberg limits			
Liquid Limit (%)	78	49	78.4
Plastic Limit (%)	41	25	41.1
Plasticity Index (%)	37	24	37.3
Compaction			
OMC (%)	14.3	12.1	12.1
MDD (gm/cc)	1.65	1.69	1.68

Source: Laboratory Analysis

As summarized in Table 1, the percentage of soils retained in No 200 BS sieve ranges between 2.5 % and 3.3%. The cumulative passing No 200 BS sieve range from 38.9% to 76.7%. therefore, there is a higher percentage of fines than sand in the soils. In line with AASHTO soil classification, soils with more than 35% passing No 200 BS sieve is classified as silty-clay materials. These soils fall within this category. Their liquid limits (LL) and plasticity indices (PI) fall within the ranges of 49% to 78.4% and 24% to 37.3% respectively. Thus, they can be said to belong to the soil group A-7-5, indicating that they are chiefly constituted of clayey soils with a fair to poor subgrade rating. Unless properly stabilized, these soils cannot be used as road subgrade materials because, only samples with less than 35% passing No 200 BS sieve can be used for subgrades in line with Federal Ministry of Works and Housing (1997) specification [7].

The OMC and MDD ranged from 12.1% to 14.3% and 1.65gm/cc to 1.69gm/cc respectively. These fell within the ranges outlined for clayey or silty-sand by [14] when using the standard Proctor test method.

3.1. California Bearing Ratio (CBR) Test

Three-point CBR values are plotted against their corresponding moisture contents in Figure 1. A clear knowledge of the ground conditions under different conditions is provided by the three-point CBR as against the conventional one-point method. The soil samples are usually prepared in three different molds of different densities and moisture contents. This gives a clear understanding of the CBR of the soils at different levels of compaction unlike the one-point approach that is very specific to a particular density and moisture content.

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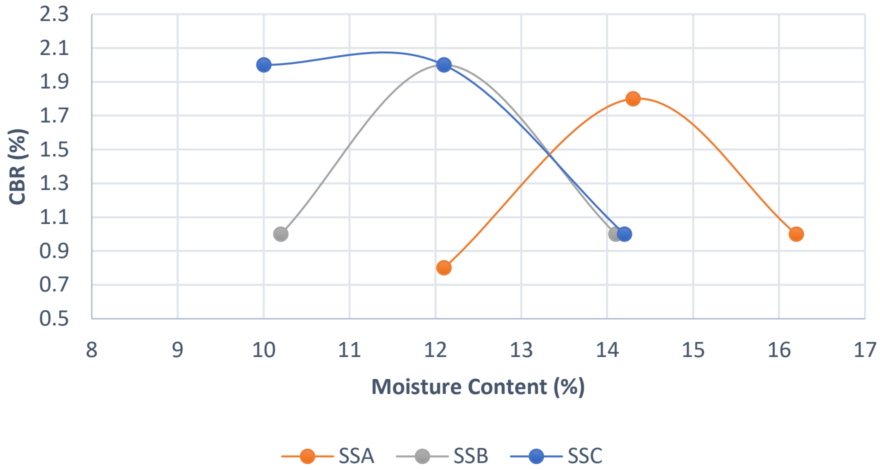

Fig. 1: CBR versus Moisture Contents for Samples SS_A, SS_B and SS_C

The CBR values at OMC for the three samples, as can be seen from Figure 1, are very closely related (1.8% - 2%). The minimum value of CBR for subgrade soils is 6%, although 10% is recommended by subgrade stabilization [5]. This buttresses the fact that these soils, in their natural conditions, are not good enough to be used as a subgrade layer. This is, perhaps, linked to the high percentage of fines as indicated in the index properties of the soils.

3.2. Correlation Analysis

Correlation coefficients measure how strongly the relative movements of two variables affects their relationship. The values of the coefficients range from -1.0 to 1.0. When the coefficient is outside this range, it means that an error must have occurred in the correlation evaluation. A value of -1.0 indicates a perfect negative correlation; when one variable increases in the opposite direction, the other decreases. Also, a perfect positive correlation is indicated by 1.0; an increase in the values of one variable results in an increase of the other. When the value is 0.0, then no linear relationship exists between the variables. A value of 0.1 to 0.39 is a weak correlation, 0.4 to 0.5 is moderate, while 0.51 to 0.9 is a strong correlation. Correlation coefficients for the relationship between the CBR and index properties of the soil samples are as tabulated in Table 2.

Table 2: Correlation between CBR and Index Properties of the Soils

Variables	*CBR (%)*	*% retained in No. 200 sieve*	*% passing through No. 200 sieve*	*Liquid Limit (%)*	*Plastic Limit (%)*	*Plasticity Index (%)*	*OMC (%)*	*MDD (gm/cc)*
CBR (%)	1.00							
% retained in No. 200 sieve	-0.41	1.00						
% passing through No. 200 sieve	-0.32	-0.73	1.00					
Liquid Limit (%)	-0.49	-0.59	0.98	1.00				
Plastic Limit (%)	-0.50	-0.59	0.98	1.00	1.00			
Plasticity Index (%)	-0.48	-0.60	0.98	1.00	1.00	1.00		
OMC (%)	-1.00	0.41	0.32	0.49	0.50	0.48	1.00	
MDD (gm/cc)	0.97	-0.18	-0.54	-0.68	-0.69	-0.68	-0.97	1.00

Source: MS Excel

It can be observed from Table 2 that there is a weak negative correlation (-0.32) between the CBR and percentage passing the No 200 BS sieve of the soils. Also, a moderate negative correlation, ranging from -0.41 to -0.5, is observed between the CBR and the

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Atterberg limits as well as the percentage retained in No 200 BS sieve. A perfect negative relationship (-1.0) exists between the CBR and OMC of the soils. Equally, a strong positive relationship exists between the CBR and MDD of the samples.

4. CONCLUSION

From the analysis of test results, the following conclusions are drawn:

1) There is a strong negative correlation (0.97) between the soils' CBR values and their maximum dry densities (MDD). Increase in MDD values resulted in corresponding increments in the CBR values.
2) The relationship between CBR and optimum moisture contents (OMC) exhibited a perfect negative correlation of -1.0. Thus, increase in OMC resulted in a decrease in the CBR values.
3) A moderate negative correlation (-0.41 to -0.5) exists between the CBR values and the Atterberg limits as well as the percentage passing No 200 BS sieve.
4) The correlation between CBR and the percentage retained in No 200 BS sieve is weak and negative (-0.32)

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Conflicts of interests

The authors declare that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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